International Endodontic Journal

doi:10.1111/j.1365-2591.2009.01578.x

Root and canal morphology of mandibular first and second molar teeth in a Jordanian population

A. A. Al-Qudah & L. A. Awawdeh

Department of Restorative Dentistry, Faculty of Dentistry, Jordan University of Science & Technology, Irbid, Jordan

Abstract

Al-Qudah AA, Awawdeh LA. Root and canal morphology of mandibular first and second molar teeth in a Jordanian population. *International Endodontic Journal*, **42**, 775–784, 2009.

Aim To examine the root and canal morphology of mandibular permanent first and second molar teeth in a Jordanian population.

Methodology A total of 685 extracted mandibular first and second permanent molar teeth were collected from dental clinics within north Jordan. The teeth were examined visually and the root number and morphology were recorded. After that, access cavities were prepared, pulp tissue dissolved by sodium hypochlorite and the root canals injected with Indian ink. Stained teeth were decalcified with 10% nitric acid, dehydrated with ascending concentrations of alcohol and rendered clear by immersion in methyl salicylate. The following observations were evaluated: (i) number of canals per root; (ii) number of root canals per tooth; (iii) canal configuration in each root; (iv) number and location of lateral canals and (v) presence of intercanal communications.

Results Of 330 mandibular first molars, the majority had three (48%) or four (46%) canals, whilst 4% had a third disto-lingual root. Of 355 mandibular second molars, 58% had three canals, 19% two and 17% had four canals, whilst 10% had C-shaped roots. The most prevalent canal configuration in the mesial root of both first (53%) and second (40%) molars was type IV, and in distal roots was type I (54% in first and 79% in second molars).

Conclusions Jordanian mandibular first and second molar teeth exhibit features close to the average Caucasian root and canal morphology.

Keywords: C-shaped canal, disto-lingual root, mandibular molars, morphology, root canal.

Received 6 March 2008; accepted 2 March 2009

Introduction

Successful root canal treatment depends on adequate debridement and filling of the entire root canal system. Such therapy may be unsuccessful because the dentist has failed to recognize the presence of an additional canal and it is important to be familiar with variations in root canal morphology as such knowledge can aid location and negotiation of canals as well as their subsequent management.

Current knowledge of root canal anatomy is based on research findings and individual case reports. Many studies have examined the root canal systems of mandibular first and second molars. Hess & Zürcher (1925) duplicated pulp space anatomy using vulcanite casts and reported that the prevalence of three root canals in mandibular permanent molar teeth was 78%. Later, Skidmore & Bjorndahl (1971) drew attention to the prevalence of four canals in approximately 29% of mandibular first molars. Al-Nazhan (1999) conducted a clinical study on root filled mandibular first molars of a Saudi Arabian population and found that 58% of teeth had four canals.

The anatomic configuration of roots and canals of mandibular first and second molars is diverse (Skidmore & Bjorndahl 1971, Pineda & Kuttler 1972, Vertucci 1984, Walker 1988a,b, Al-Nazhan 1999, Wasti *et al.* 2001, Gulabivala *et al.* 2001, 2002, Sert *et al.* 2004). The differences may be related to study design (*in vivo* versus *in vitro*), technique of canal

Correspondence: Dr Aladdin Al-Qudah, BDS, FDSRCPS (Glasg), PhD, Jordanian board (endo), IQE. Department of Conservative Dentistry, Faculty of Dentistry, Jordan University of Science & Technology, PO Box 3030, Irbid 22110, Jordan (Fax: 00962-2-7095115; e-mail: aqudah@just.edu.jo).

identification (radiographic examination, sectioning and clearing) or to racial divergence. To date, a number of studies have reported that root canal systems vary according to race (Walker 1988a,b, Weine *et al.* 1988, Al-Nazhan 1999, Wasti *et al.* 2001, Sert & Bayirli 2004, De Moor *et al.* 2004, Awawdeh & Al-Qudah 2008, Awawdeh *et al.* 2008). These variations appear to be genetically determined (Sperber 1990). A variation that has received particular attention is the mandibular first molar with three roots. This variant has a frequency of less than 5% in Caucasian, African and Eurasian populations, whereas in those with Mongoloid traits, such as Chinese it occurs with frequency of 5 to more than 40% (De Moor *et al.* 2004). Another reported variation is the 'C-shaped root and canal configuration'. Seldom found in Caucasian populations (Weine *et al.* 1988), they have a relatively high prevalence in Chinese and Korean populations (Walker 1988a,b, Seo & Park 2004).

Descriptions of the frequently occurring root canal systems of permanent teeth, related to teeth of mainly Caucasoid origin, are based largely on studies conducted in Europe and North America. These descriptions may not be fully applicable to teeth of non-Caucasoid origin. There are no published reports, on root and canal morphology of mandibular molars, in Jordan, and only few reports, about specific morphological features, in other Middle Eastern countries. The purpose of this study was to examine the root and canal morphology of mandibular permanent first and second molars in a Jordanian population, using canal staining and root clearing techniques.

Materials and methods

The sample teeth comprised 330 mandibular first and 355 mandibular second permanent molars extracted from Jordanian patients attending various dental clinics within north Jordan. The age, gender and reason for extraction were not recorded. Dentists were provided with containers and asked to include teeth extracted only from Jordanian patients. Dentists were informed that the collected teeth were to be used for research purposes. The teeth were collected over a 2-year period and stored in 10% formalin solution until the start of the investigation. Patients gave informed verbal consent for extraction; in accordance with the guidelines governing the practice of dentistry in Jordan.

The identification of the teeth as mandibular first and second molars was based on crown morphology according to accepted criteria (Ash 1985). The teeth were placed in 3.25% sodium hypochlorite (Hypex Bleach; Jordan Chemical industries Co., Amman, Jordan) for 2 h, after which any remaining soft tissue or calculus was removed by scaling. The cleaned teeth were examined visually and the number of roots and their morphology recorded. After that, endodontic access cavities were prepared and the pulp tissue removed by immersion in 3.25% sodium hypochlorite overnight, before placement in an ultrasonic bath. The teeth were then rinsed under running tap water for 2 h and dried overnight. An endodontic irrigation syringe with a 27 gauge needle (BU Kwang Medical Inc., Seoul, Korea) was used to inject Indian ink (Sanford rotring GmbH, Hamburg, Germany) into the root canal system. The root apex was then immediately connected to a central suction system, until the ink exited through the apical foramina.

The teeth were demineralized by immersion in 10% nitric acid for 4 days and then in 5% acid for 1–6 days. The acid solution was changed daily and the teeth were assessed for softness by inserting a needle in the crown. The teeth were washed under running tap water for 4 h, dried and dehydrated using ascending concentrations of ethyl alcohol (70%, 96% and 99%) for 12 h each. Finally, the dehydrated teeth were placed in methyl salicylate which rendered them transparent after about 2 h.

The transparent specimens were examined by the naked eye beneath halogen light and the following observations were made: (i) number of root canals per root (defined as the highest number of canals visualized); (ii) number of root canals per tooth; (iii) root canal configuration in each root; (iv) presence and location of lateral canals and intercanal communications. Lateral canals were defined as those branches of main canals that diverged at right or oblique angles to exit on the lateral aspect of the root. The canal configurations were categorized using Vertucci's classification (2005) with additional modifications as follows:

Type I. A single canal is present from the pulp chamber to the apex.

Type II. Two separate canals leave the pulp chamber, but join to form one canal to the site of exiting.

Type III. One canal leaves the pulp chamber, divides into two within the root and then merges to exit in one canal.

Type IV. Two separate and distinct canals are present from the pulp chamber to the apex.

Type V. Single canal leaving the pulp chamber but dividing into two separate canals with two separate apical foramina.

Type VI. Two separate canals leave the pulp chamber, but join at mid-point and divides again into two separate canals with two separate apical foramina.
Type VII. One canal leaves the pulp chamber, divides and rejoins within the root, and finally redivides into two separate canals short of the apex.
Type VIII. Three separate and distinct canals extend from pulp chamber to root apex.

Additional types:

Type (2-1-2-1). Two separate canals leave the pulp chamber, join at mid-point and divide again into two separate canals and then merge to exit as a single canal.

Type (2-3). Two separate canals leave the pulp chamber, and then one divides further into two canals giving a total of three separate canals with three separate apical foramina.

Type (2-3-1). Two separate canals leave the pulp chamber, and then one divides further into two giving a total of three canals, which finally merge to exit as a single canal.

Type (2-3-2). Two separate canals leave the pulp chamber, and then one divides further into two which again rejoin, giving two canals with two separate foramina.

Type (3-1). Three separate canals leave the pulp chamber, but join to form one canal to the site of exiting.

Type (3-2). Three separate canals leave the pulp chamber, and then two of them join into one giving two canals with two separate foramina.

Type (3-2-1). Three separate canals leave the pulp chamber, and then two of them join into one giving two canals which then merge to exit as a single canal.

Type (3-2-3). Three separate canals leave the pulp chamber, and then two of them join into one which divides again giving a total of three separate canals with three separate apical foramina.

Results

Number of roots and their morphology

The data for number of roots and their morphology are presented in Table 1. The majority (96%) of the 330 mandibular first molars had two roots, which were either separate (95%) or fused (1%). Three roots were observed in 4% of first molars with the extra root lingual to the main distal root. Of the 355 mandibular second molars, 82% had two separate roots, whilst 10% were C-shaped and the rest either had two fused roots (5%) or a single conical root (2%).

Table 1 Classification of mandibular first and second molars by root number and morphology

Group	Description	First molar *n* = 330	Second molar *n* = 355
I	Two separate roots	314 (95.2)	291 (82)
II	Two fused roots	3 (0.9)	19 (5.4)
III	Three separate roots	13 (3.9)	0
IV	Single C-shaped root	0	37 (10.4)
V	Single conical root	0	8 (2.3)

Number and type of canal system

The data for canal number and configuration are given in Tables 2–5

Mandibular first molar

The majority of mandibular first molars had three (48%) or four (46%) canals. The remainder had either five canals (6%) or two canals (1%). A total of 307 teeth (93%) had two mesial canals and demonstrated a wide variation of canal configurations (see Figs 1 and 2a,b). The most common were type IV (174–53%) and type II (119–36%). Twenty teeth (6%) had three mesial canals (type VIII, 2-3, 2-3-1, 2-3-2, 3-1, 3-2, 3-2-1 and 3-2-3) and only three teeth (1%) had one mesial canal. In mesial roots with type 2-3 configuration, the buccal canal further divided into two in 60% and the lingual in 40% of samples. In type 3-2-3 configuration, the joining and further division of canals occurred in the middle third of the root.

Of the distal roots, 54% had one canal and 45% had two canals of which type II (17%), type V (11%) and type IV (9%) were most prevalent. Only four distal roots (1%) had three canals. In distal roots with type 2-3 configuration, the buccal canal further divided into two in all samples.

In the three rooted molars, all disto-lingual roots (100%) possessed type I canal configuration.

Mandibular second molars

The majority (58%) of mandibular second molars had three canals, whilst 19% had two canals and 17% had four canals. The remainder had either one canal (5%) or five canals (2%). Most distal roots (79%) in the two-rooted molars had only one canal. Of the mesial roots, 81% had two canals, of which type IV (40%) and type II (33%) canal configurations were most prevalent. In mesial roots with type 2-3 configuration, the buccal canal further divided into two in all samples.

Table 2 Number and percentage of mandibular first and second molars with 1, 2, 3, 4 or 5 canals per tooth

		No. canals per tooth				
Type of molar	No. teeth	1	2	3	4	5
First molars	330	0	2(0.6%)	159(48.2%)	151(45.8%)	18(5.5%)
Second molar	355	16(4.5%)	67(18.9%)	207(58.3%)	59(16.6%)	6(1.7%)

Table 3 Number and percentage of canal system types in 330 mandibular first molars

	Types															
Group (no. teeth)	I	II	III	IV	V	VI	VII	VIII	2-1-2-1	2-3	2-3-1	2-3-2	3-1	3-2	3-2-1	3-2-3
2 roots (317)																
M root	2	113	2	168	3	9	–	1	–	5	2	3	2	4	1	2
	0.6%	34.2%	0.6%	50.9%	0.9%	2.7%		0.3%		1.5%	0.6%	0.9%	0.6%	1.2%	0.3%	0.6%
D root	168	56	15	30	36	4	2	–	2	3	–	–	1	–	–	–
	50.9%	17%	4.5%	9.1%	10.9%	1.2%	0.6%		0.6%	0.9%			0.3%			
3 roots (13)																
M root	1	6	–	6	–	–	–	–	–	–	–	–	–	–	–	–
	0.3%	1.8%		1.8%												
D root	11	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–
	3.3%		0.3%	0.3%												
DL root	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	100%															

Table 4 Number and percentage of canal system types in 355 mandibular second molars

	Types												
Group (no. teeth)	I	II	III	IV	V	VI	VIII	2-1-2-1	2-3	2-3-1	2-3-2	3-2	3-2-1
2 roots (310)													
M root	50	101	11	125	11	3	1	–	2	1	3	1	1
	16.1%	32.6%	3.5%	40.3%	3.5%	1.0%	0.3%		0.6%	0.3%	1.0%	0.3%	0.3%
D root	245	24	8	14	17	–	–	1	–	–	1	–	–
	79.0%	7.7%	2.6%	4.5%	5.5%			0.3%			0.3%		
C-shaped root (37)	8	–	–	18	–	–	2	–	3	–	–	6	–
	21.6%			48.6%			5.4%		8.1%			16.2%	
Conical root (8)	8	–	–	–	–	–	–	–	–	–	–	–	–
	100%												

Table 5 Number and percentage of roots with lateral canals and intercanal communications and their distribution along different levels of the root

		No. and % of lateral canals			No. and % Intercanal communications		
Type of molar	No. roots	Coronal third	Middle third	Apical third	Coronal third	Middle third	Apical third
First molars							
M root	330	–	2 (0.6)	1 (0.3)	29 (8.8)	51 (15.5)	43 (13.0)
D root	330	–	–	10 (3.0)	11 (3.3)	25 (7.6)	7 (2.1)
Second molars							
M root	300	–	1 (0.3)	5 (1.7)	17 (5.7)	45 (15.0)	29 (9.7)
D root	300	–	2 (0.7)	5 (1.7)	3 (1.0)	7 (2.3)	4 (1.3)
C-shaped	37	–	–	–	1 (2.7)	3 (8.1)	7 (18.9)

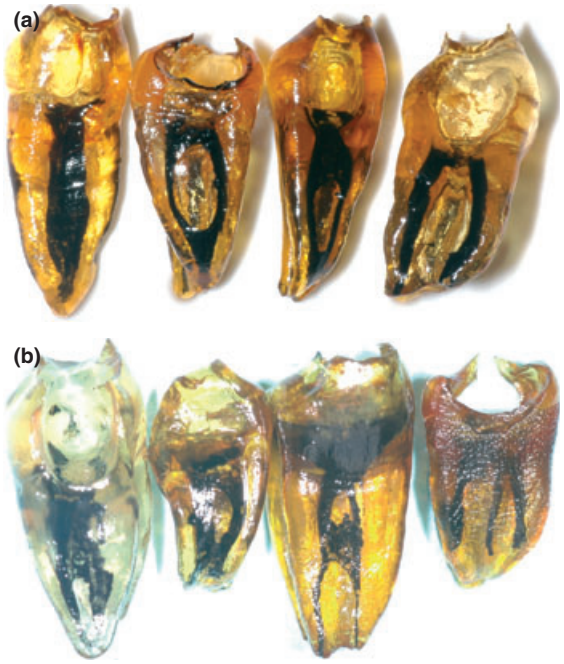

Figure 1 Canal configurations observed in this study. (a) From left to right: type I, II, III, and IV. (b) From left to right: type V, VI, VII, and VIII.

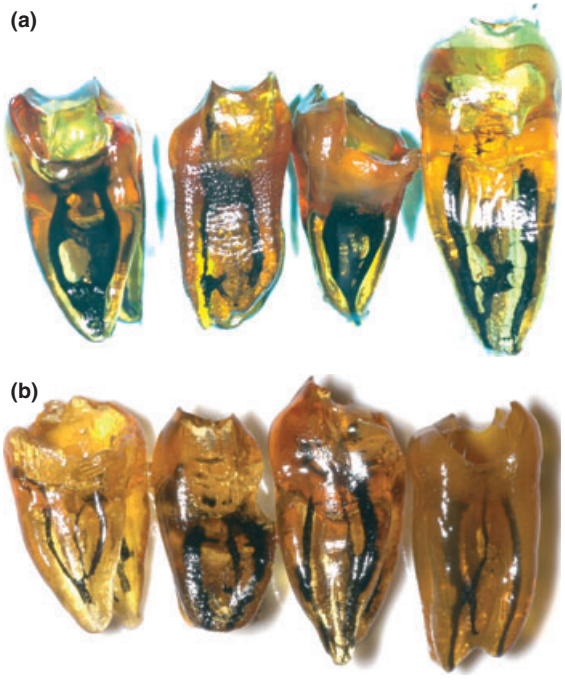

Figure 2 Additional canal configurations observed in this study. (a) From left to right: type 2-1-2-1, 2-3, 2-3-1 and 2-3-2. (b) From left to right: type 3-1, 3-2, 3-2-1 and 3-2-3.

Teeth with C-shaped roots had either two (49%), three (30%) or one canal (22%). All teeth with single conical root (100%) contained type I canal configuration.

Discussion

A variety of techniques have been used to study root canal morphology including radiographic examination (Omer *et al.* 2004), root sectioning (Jung *et al.* 2005), micro-computed tomography (Mannocci *et al.* 2005) and staining and clearing techniques (Robertson *et al.* 1980). It has been reported that fine details of the root canal system can be visualized by staining and clearing (Gulabivala *et al.* 2002, Al-Qudah & Awawdeh 2006) and this method was used in this study and found to be adequate for three–dimensional evaluation of root canal morphology.

The tooth designation was not recorded at the time of extraction as they were not individually stored and labelled. Nevertheless, differentiation into first and second molars, based on crown morphology, proved straightforward. The clear trends in anatomical differences between tooth types confirm this. The reasons for extraction were not known as teeth were collected over 2-year period and it was difficult for dentists, who volunteered to provide teeth, to report this data over the collection period. However, teeth were extracted by qualified dentists who are licensed to practice dentistry by the Jordanian Ministry of Health. It is anticipated that the main reasons for extraction were advanced periodontal disease and prosthodontic rehabilitation.

This study examined the root and canal morphology of extracted mandibular first and second molars collected from dental clinics within north Jordan. Therefore, the sample may not be fully representative of the Jordanian population. However, root and canal morphology may not vary in a young nation of the same ethnic origin. Therefore, the data presented in this paper is expected to apply to the Jordanian population in general.

It is worth mentioning that large number of first (330) and second (355) mandibular molars was used in this study as compared with many previous investigations (Walker 1988a,b, Gulabivala *et al.* 2001, Wasti *et al.* 2001, Gulabivala *et al.* 2002, Ahmed *et al.* 2007). Increasing the sample of teeth studied can result in more consistent and reliable data, leading to a clear conclusion about the common morphological characteristics of these teeth. The large number of teeth is also particularly important when studying the less common

anatomic variations like the disto-lingual root in first molars and the C-shaped canals in second molars.

Mandibular first molars

The prevalence of three roots in mandibular first molars of north Jordanian population (4%) is comparable with the figure (3%) reported by Ahmed *et al.* (2007) for a Sudanese population and to that (3%) reported by Sperber & Moreau (1998) for a Senegalese population. It is also similar to the findings of Curzon (1973) who reported that 3% of mandibular first molars in an English Caucasian population had three roots. However, it is lower than the figure reported for Burmese (10%), Thai (13%), Southern Chinese (15%) and Aleut Eskimo (32%) populations (Turner 1971, Walker 1988a,b, Gulabivala *et al.* 2001, 2002). The additional root was found on the lingual aspect of the main distal root and has been called the disto-lingual root. It was hypothesized that the presence of this third root adds to the stability of mandibular first molars by increasing root surface area attached to the alveolar bone. This added retention, may have been necessary in traditional cultures to meet the heavy demand placed upon the dentition. The continued presence of this root indicates that it is a genetically determined racial trait rather than a developmental anomaly (Walker 1988a,b). The clinical consequences of a disto-lingual root in the mandibular first molar are important in root canal treatment. The requirement for cleaning, shaping and filling more than the usual three or four canals, during root canal treatment of mandibular first molars, is self-evident.

The work of Skidmore & Bjorndahl (1971) drew the dental profession's attention to the prevalence of a fourth canal in approximately 29% of mandibular first molars. This finding was subsequently substantiated by Pineda & Kuttler (1972) and Vertucci & Williams (1974). In this study, the frequency of four canals is higher and approaches one-half (46%) of teeth examined. This is consistent with the findings of Walker (1988a,b), Wasti *et al.* (2001) and Sert *et al.* (2004) who reported four canals in 45%, 47% and 46% of mandibular first molars respectively. However, the percentage is higher than the figure (30%) reported by Vertucci (1984), the (31%) by Gulabivala *et al.* (2002) and the (25%) reported by Sperber & Moreau (1998). The lower prevalence of four canals reported by Gulabivala *et al.* (2002), compared with this study, can be explained by the way in which number of root canals was reported. In their study, the number of root canals was defined as root canal orifices in the pulp chamber, whereas in this study it is defined as the highest number of canals visualized. Therefore, in their study, roots with type III, V and VII canal configurations were considered as having only one canal, whereas in this study, they were considered as having two canals. If the method of Gulabivala *et al.* (2002) for counting canals was followed in this study, then only 29% (type II, IV, VI, 2-1-2-1 and 2-3) of distal roots contained two canals and consequently, four canals would be reported in only 29% of teeth, which is comparable with the figure (31%) reported by Gulabivala *et al.* (2002). However, the method used in this study may be considered more accurate, because it does not ignore the presence of canals in the middle of the root, which should be negotiated, cleaned, shaped and filled for optimal treatment outcome. The staining and clearing techniques allowed visualization of such canals, and not only the distinct canals starting in the pulp chamber.

In the mesial root, the type IV configuration was most prevalent (53%), followed by type II (36%) canal configuration. This is consistent with the findings of Vertucci (1984) who reported a prevalence of 51% and 28% for type IV and type II configurations respectively. Of the remaining 11%, 6% had three canals, 1% had one canal and 4% had two canals of variable configurations as shown in Table 3. Identification, preparation and filling of type IV canal system are relatively straightforward because each of the canals is separate and distinct between orifice and apex. Identification of canals in the type II configuration is also straightforward because two distinct canals leave the pulp chamber. However, identification of canals in type III, V and other configurations, where the canal further divides within the root, is more difficult. Location and negotiation of such canal configurations may be aided by the use of dental-operating microscope. Several studies have shown that it significantly increases the dentist's ability to locate and negotiate canals (Coelho de Carvalho & Zuolo 2000, Görduysus *et al.* 2001, Schwarze *et al.* 2002). In addition, apical canal branches may be more readily found and negotiated by early coronal flaring. However, in clinical practice, these measures may not be successful, and therefore, dentists may negotiate, prepare and fill only two canals in type 2-3, 2-3-1 and 2-3-2 configurations and miss the third canal space. Similarly, one canal only may be negotiated, prepared and filled in type III and V configurations. The results of this study demonstrate that such canal configurations in the mesial roots of

mandibular first molars are rare and collectively account for only 5% of the roots. Nevertheless, such canal configurations may account for some cases of unexplained treatment failure in teeth with radiographically adequate root fillings. This is because considerable canal space may be left uninstrumented and unfilled in such configurations.

The most prevalent canal configuration in the distal root was type I (54%) followed by type II, V, IV, III and other configurations as shown in Table 3. Although two canals were found in 45% of distal roots, only 22% of the roots had two separate apical foramina and this agrees with the findings of other studies (Walker 1988a,b, Wasti *et al.* 2001, Sert *et al.* 2004, Ahmed *et al.* 2007). The low percentage of two apical foramina conforms to the external morphology of the distal root which is more rounded than the mesial one and therefore less likely to accommodate two separate canals.

In this study, lateral canals were found in 1% of mesial and 3% of distal roots of first molars and were most prevalent in the apical third of distal root as shown in Table 5. This is comparable with the findings of Gulabivala *et al.* (2002) who reported lateral canals in 3% of the roots of mandibular first molars. Intercanal communications were observed in 37% of mesial roots of first molars. The high percentage of intercanal communications may be of clinical significance, because it may be difficult to debride and fill these communications adequately. However, the use of sodium hypochlorite, preferably agitated by ultrasonics may help to reach the uninstrumented parts of the root canal system (Reynolds *et al.* 1987).

Mandibular second molars

The majority (82%) of the examined teeth had two separate roots, whilst 10% were C-shaped and the rest had either two fused roots (5%) or a single conical root (2%). These findings agree with those of Gulabivala *et al.* (2002) who examined 60 mandibular second molars from a Thai population and reported that 90% of teeth had two separate roots and 10% had C-shaped roots. However, they are different from those of Gulabivala *et al.* (2001) who studied Burmese mandibular molars and determined a prevalence of 58% and 22% for two separate roots and C-shaped roots respectively.

A C-shaped canal appears when fusion of either the buccal or lingual aspect of mesial and distal roots occurs and the two roots stay connected by an interradicular ribbon or web. The pulp chamber does not have individually distinct canal orifices but rather a C-shaped trough on its floor (see Fig. 3).

C-shaped canals were first documented by Cooke & Cox (1979) in three case reports. Subsequent studies of canal morphology of mandibular second molars from Japanese (Kotoku 1985), Chinese (Walker 1988a,b, Yang *et al.* 1988) and Korean (Seo & Park 2004) populations revealed a high incidence of C-shaped roots and canals (14–52%). It has thus been reported that this particular anatomy is more common in populations of Mongoloid origin. In this study, the prevalence of 10% in Jordanian mandibular second molars is lower than that in Mongoloid populations but similar to the figure (10%) reported for both Sudanese (Ahmed *et al.* 2007) and Saudi Arabian populations (Al-Fouzan 2002).

Manning (1990) reported that C-shaped roots most frequently had three canals. Other studies have reported a more diverse range of canal systems in C-shaped roots (Haddad *et al.* 1999, Al-Fouzan 2002, Cheung *et al.* 2007). In this study, about one-half (49%) of the C-shaped roots had two canals, about one-third (30%) had three canals; the remaining 22% possessed a single canal.

Of the two-rooted mandibular second molars, 79% had a single distal canal and 81% had two mesial canals. This is similar to the findings of Sert *et al.* (2004) who reported that 76% of distal roots of mandibular second molars, in a Turkish population, had a single canal and 88% of mesial roots had two canals. These results are also similar to those of Gulabivala *et al.* (2002) for a Thai population but different from those of Gulabivala *et al.* (2001) for a

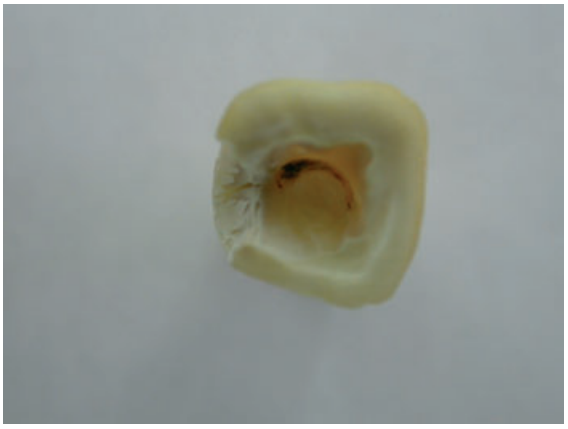

Figure 3 Occlusal access cavity view showing C-shaped canal.

Burmese population. In both mandibular first and second molars, the commonest canal configuration was type IV in the mesial roots and type I in the distal roots. However, the prevalence of type I was considerably higher in distal roots of second molars and that of type IV higher in mesial roots of first molars.

In this study, two or more canals were found in 46% and 21% of distal roots of mandibular first and second molars respectively. These findings are higher than the classical figures (30%) and (8%) reported in most Endodontic textbooks (Walton & Vertucci 2002, Saunders & Saunders 2003, Weine 2004, Vertucci *et al.* 2006). The high frequency of a fourth canal in mandibular first and second molars makes it essential to anticipate and find all canals during root canal treatment of these teeth. The use of dental operating microscope and fiberoptic endoscope may allow easier location of such canals.

Many of the recent studies reported higher prevalence of second distal canal (45–59%) in first (Walker 1988a,b, Wasti *et al.* 2001, Sert *et al.* 2004, Ahmed *et al.* 2007) and (21–29.6%) in second molars (Gulabivala *et al.* 2002, Sert *et al.* 2004, Ahmed *et al.* 2007), than stated in Endodontic textbooks. Therefore, it may be recommended to update the figures commonly reported in Endodontic textbooks in light of the newly published reports of root canal morphology. However, the prevalence of two separate canals leaving the pulp chamber (type II, IV, VI, 2-1-2-1, 2-3, 2-3-1, 2-3-2), in the distal root of first and second mandibular molars, was 29% and 13% respectively. Therefore, the results of this study indicate that the chance of finding two canal orifices in the distal border of the floor of pulp chamber is 29% in first and 13% in second mandibular molars. Nevertheless, every effort should be made to locate and negotiate canals in the other 'branched configurations' as these account for a substantial proportion of canal system types found in this study. Inability to negotiate, prepare and fill such configurations may account for some cases of unexplained treatment failures in teeth with radiographically adequate root fillings.

This study, to investigate root and canal morphology of mandibular first and second molars in Jordanian population, was motivated by the lack of published work. It details the various root canal morphological features of these teeth in this population. It also emphasizes the high frequency of four canals in mandibular first molars, as well as the presence and clinical significance of the less common canal configurations. In addition, comparisons were made with the results of other studies on different populations and factors accounting for differences highlighted. Of particular significance in this regard is the criteria used to report the number of canals in each root. A large number of teeth were evaluated as this can result in more consistent and reliable data and minimize the chance of error leading to clear conclusions about common morphological features of these teeth. This is also particularly important when studying the less common anatomic variations such as the disto-lingual root, C-shaped canals and branched canal configurations.

Conclusions

The root and canal morphology of 685 Jordanian mandibular first and second molars were examined. The findings are, on the whole, comparable with other studies. The prevalence of three roots was 4% and C-shaped roots 10% in first and second molars respectively. The majority of first molars had three (48%) or four (46%) canals, whilst 58% of second molars had three canals, 19% two canals and 17% possessed four canals. The most prevalent canal configuration in the mesial root of first and second molars was type IV and in distal root type I configuration. Clinicians should be aware of branched canal configurations in mandibular first and second molars and use all available armamentarium to achieve successful outcome.

Acknowledgement

The authors wish to thank Jordan University of Science and Technology for supporting this project financially.

References

Ahmed HA, Abu-bakr NH, Yahia NA, Ibrahim YE (2007) Root and canal morphology of permanent mandibular molars in a Sudanese population. *International Endodontic Journal* **40**, 766–71.

Al-Fouzan KS (2002) C-shaped root canals in mandibular second molars in a Saudi Arabian population. *International Endodontic Journal* **35**, 499–504.

Al-Nazhan S (1999) Incidence of four canals in root-canal treated mandibular first molars in a Saudi Arabian subpopulation. *International Endodontic Journal* **32**, 49–52.

Al-Qudah AA, Awawdeh LA (2006) Root canal morphology of mandibular incisors in Jordanian population. *International Endodontic Journal* **39**, 1–5.

Ash MM (1985) *Wheeler's Dental Anatomy, Physiology and Occlusion*, 6th edn. London: Saunders Company, pp. 245–75.

Awawdeh LA, Al-Qudah AA (2008) Root form and canal morphology of mandibular premolars in a Jordanian population. *International Endodontic Journal* **41**, 240–8.

Awawdeh L, Abdullah H, Al-Qudah A (2008) Root form and canal morphology of Jordanian maxillary first premolars. *Journal of Endodontics* **34**, 956–61.

Cheung GS, Yang J, Fan B (2007) Morphometric study of the apical anatomy of C-shaped root canal systems in mandibular second molars. *International Endodontic Journal* **40**, 239–46.

Coelho de Carvalho MC, Zuolo ML (2000) Orifice locating with a microscope. *Journal of Endododontics* **26**, 532–4.

Cooke HG, Cox FL (1979) C-shaped canal configurations in mandibular molars. *Journal of the American Dental Association* **90**, 836–9.

Curzon MEJ (1973) Three-rooted mandibular permanent molars in English Caucasians. *Journal of Dental Research* **52**, 181.

De Moor RJ, Deroose CA, Calberon FL (2004) The radix entomolaris in mandibular first molars: an endodontic challenge. *International Endodontic Journal* **37**, 789–99.

Görduysus MO, Gorduysus M, Friedman S (2001) Operating microscope improves negotiation of second mesiobuccal canals in maxillary molars. *Journal of Endodontics* **27**, 683–6.

Gulabivala K, Aung TH, Ng Y-L, Alavi A (2001) Root and canal morphology of Burmese mandibular molars. *International Endodontic Journal* **34**, 359–70.

Gulabivala K, Opasanon A, Ng Y-L, Alavi A (2002) Root and canal morphology of Thai mandibular molars. *International Endodontic Journal* **35**, 56–62.

Haddad GY, Nehme WB, Ounsi HF (1999) Diagnosis, classification and frequency of C-shaped canals in mandibular second molars in the Lebanese population. *Journal of Endodontics* **25**, 268–71.

Hess W, Zürcher E (1925) *The Anatomy of Root Canals of the Teeth of the Permanent and Deciduous Dentitions*. New York: William Wood & Co.

Jung IY, Seo MA, Fouad AF *et al.* (2005) Apical anatomy in mesial and mesiobuccal roots of permanent first molars. *Journal of Endodontics* **31**, 364–8.

Kotoku K (1985) Morphological studies on the roots of the Japanese mandibular second molars. *Shikwa Gakuho* **85**, 43–64.

Manning SA (1990) Root canal anatomy of mandibular second molars. Part II. C-shaped canals. *International Endodontic Journal* **23**, 40–5.

Mannocci F, Peru M, Sherriff M, Cook R, Pitt Ford TR (2005) The isthmuses of the mesial root of mandibular molars: a micro-computed tomographic study. *International Endodontic Journal* **38**, 558–63.

Omer OE, Al Shalabi RM, Jennings M, Glennon J, Claffey NM (2004) A comparison between clearing and radiographic techniques in the study of root canal anatomy of maxillary first and second molars. *International Endodontic Journal* **37**, 291–6.

Pineda F, Kuttler Y (1972) Mesiodistal and buccolingual roentgenographic investigation of 7275 root canals. *Oral Surgery* **33**, 101–10.

Reynolds MA, Madison S, Walton RE, Krell K, Rittman BR (1987) An *in vitro* histological comparison of the step-back, sonic and ultrasonic instrumentation techniques in small, curved root canals. *Journal of Endodontics* **13**, 307–14.

Robertson D, Leeb J, McKee M, Brewer E (1980) A clearing technique for the study of root canal systems. *Journal of Endodontics* **6**, 421–4.

Saunders WP, Saunders E (2003) Root canal instrumentation. In: Bergenholtz C, Bindslev PH, Reit C, eds. *Textbook of Endodontology*, 1st edn. Oxford, Malden, MA: Blackwell Munksgaard, pp. 236–60.

Schwarze T, Baethge C, Stecher T, Geurtsen W (2002) Identification of second canals in the mesiobuccal root of maxillary first and second molars using magnifying loupes or an operating microscope. *Australian Endodontic Journal* **28**, 57–60.

Seo MS, Park DS (2004) C-shaped root canals of mandibular second molars in a Korean population: clinical observation and in vitro analysis. *International Endodontic Journal* **37**, 139–44.

Sert S, Bayirli GS (2004) Evaluation of the root canal configurations of the mandibular and maxillary permanent teeth by gender in the Turkish population. *Journal of Endodontics* **30**, 391–8.

Sert S, Aslanalp V, Tanalp J (2004) Investigation of the root canal configurations of mandibular permanent teeth in the Turkish population. *International Endodontic Journal* **37**, 494–9.

Skidmore AE, Bjorndahl AM (1971) Root canal morphology of the human mandibular first molar. *Oral Surgery, Oral Medicine and Oral Pathology* **32**, 778–84.

Sperber GH (1990) The phylogeny and odontogeny of dental morphology. In: Sperber GH, ed. *From Apes to Angels*. New York: Wiley-Liss, pp. 215–9.

Sperber GH, Moreau JL (1998) Study of the number of roots and canals in Senegalese first permanent mandibular molars. *International Endodontic Journal* **31**, 112–6.

Turner CG (1971) Three-rooted mandibular first permanent molars and the question of American Indians' origins. *American Journal of Physical Anthropology* **34**, 229–42.

Vertucci FJ (1984) Root canal anatomy of the human permanent teeth. *Oral Surgery* **58**, 589–99.

Vertucci FJ, Williams RG (1974) Root canal anatomy of the mandibular first molars. *Journal of the New Jersey Dental Association* **45**, 27–8.

Vertucci FJ, Haddix JE, Britto LR (2006) Tooth morphology and access cavity preparation. In: Cohen S, Hargreaves KM, eds. *Pathways of the Pulp*, 9th edn. St Louis, MO: Mosby Elsevier, pp. 148–232.

Walker RT (1988a) Root form and canal anatomy of mandibular first molars in a southern Chinese population. *Endodontics and Dental Traumatology* **4**, 19–21.

Walker RT (1988b) Root form and canal anatomy of mandibular second molars in a Southern Chinese population. *Journal of Endodontics* **14**, 325–9.

Walton RE, Vertucci FJ (2002) Internal anatomy. In: Walton RE, Torabinejad M, eds. *Principles and Practice of Endodontics*, 3rd edn. Philadelphia, PA: W.B. Saunders Co, pp. 166–81.

Wasti F, Shearer AC, Wilson NH (2001) Root canal systems of the mandibular and maxillary first permanent molar teeth of South Asian Pakistanis. *International Endodontic Journal* **34**, 263–6.

Weine FS (2004) Initiating Endodontic treatment. In: Weine FS, ed. *Endodontic Therapy*, 6th edn. St Louis, MO: Mosby Elsevier, pp. 104–63.

Weine FS, Pasiewicz RA, Rice RT (1988) Canal configuration of the mandibular second molar using a clinically oriented *in vitro* method. *Journal of Endodontics* **14**, 207–13.

Yang ZP, Yang SF, Lin YC, Shay JC, Chi CY (1988) C-shape root canals in mandibular second molars in a Chinese population. *Endodontics and Dental Traumatology* **3**, 160–3.

